Improving Switching Performance of Power MOSFETs

Edward G. Cook
(925) 422-7871
cook5@llnl.gov

As their switching and power handling characteristics improve, solid-state devices are finding new applications in pulsed power. This is particularly true of applications that require fast trains of short-duration pulses. High-voltage (600 to 1200 V) metal-oxide-semiconductor field-effect transistors (MOSFETs) are especially well suited for use in these systems, as they can switch at significant peak power levels and are easily gated on and off very quickly. MOSFET operation at the shortest pulse durations is not constrained by the intrinsic capabilities of the MOSFET, but rather by the capabilities of the gate drive circuit and the system physical layout. This project sought to improve MOSFET operation in a pulsed power context by addressing these issues.

Project Goals

The primary goal of this project is to improve the switching performance of power MOSFETs for use in high rep-rate, short-pulse, high-power applications by improving the configuration of the gate-drive circuits and the circuit layouts used in these systems. This requires evaluation of new commercial gate-drive circuits and upgrading LLNL-created circuits. In addition, these circuits must be tested with the fastest available high-voltage power MOSFETs.

Relevance to LLNL Mission

Solid-state pulsed-power circuits are replacing older technology devices such as vacuum tubes and thyratrons, which have availability and reliability issues. This is especially true in a number of

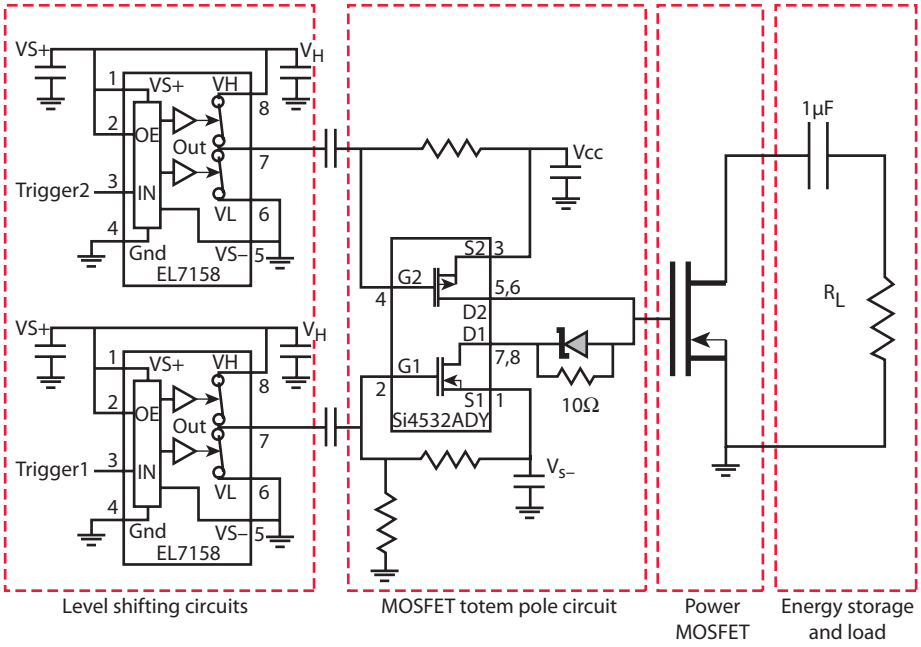

Figure 1. MOSFET gate-drive test circuit.

LLNL programs, such as the accelerator and laser efforts, where MOSFET-switched inductive adder circuits allow detailed control of voltage waveforms that would be impossible with the previous technology. Fast solid-state pulsed power is therefore an enabling technology that finds applications in both new and existing programs at LLNL, which frequently push the limits of switching speeds and short-duration pulses.

FY2006 Accomplishments and Results

We have identified several commercial gate-drive devices that exhibit excellent stability and are capable of generating pulses with fast rise and fall times and at high burst frequencies. These devices are very useful for many pulsed-power applications. However, these commercial circuits are inherently incapable of generating pulses of very short pulse duration. Their internal structure limits the minimum pulse width to a value that maintains stable operation and prevents the production of oscillating gate-drive pulses.

In an effort to generate shorter duration pulses, we have turned to an LLNL circuit composed of discrete components, as shown in Fig. 1. This circuit uses commercially available level shifting components and discrete MOSFETs arranged in a totem-pole configuration. To achieve the best control, multiple independent trigger pulses are used to overcome the limitations of turn-on and turn-off delays, shoot-through, and the MOSFET Miller capacitance.

The best of the commercial gate-drive circuits are capable of generating pulses having a minimum pulse duration (measured at the base of the pulse) of 12 to 16 ns. With the LLNL gate-drive circuit layout, we have been able to reduce the minimum pulse width to 5 ns with rise and fall times (10 to 90%) of less than 2 ns. Results are shown in Fig. 2. The switching speeds of this circuit, as measured by rise and fall times, are approximately twice as fast as those achieved with the commercial circuits. Additionally, we have operated this circuit at burst frequencies of 3 MHz for 50 pulse bursts with no degradation in the measured waveforms. This level of gate-drive circuit performance can only be realized when operated with MOSFETs that are optimized for high-frequency or pulse applications. In this respect, the gate-drive circuit and the power MOSFET should be considered to be an integrated system.

The ultimate result of this project has been that the gate-drive circuit and its associated knowledge base have entered the arsenal of LLNL capabilities that are available, as needed, to its programs. For example, the circuit is presently being refined prior to final implementation in the Kicker Pulser of the International Linear Collider so that it can provide 3- to 4-ns pulses with rise and fall times of 1 ns over a wide operating range.

Related References

1. Hickman, B. C., and E. G. Cook, "Evaluation of MOSFETs and IGBTs for Pulsed Power Applications," *International Pulsed Power Conference*, Hollywood, California, June 2001.

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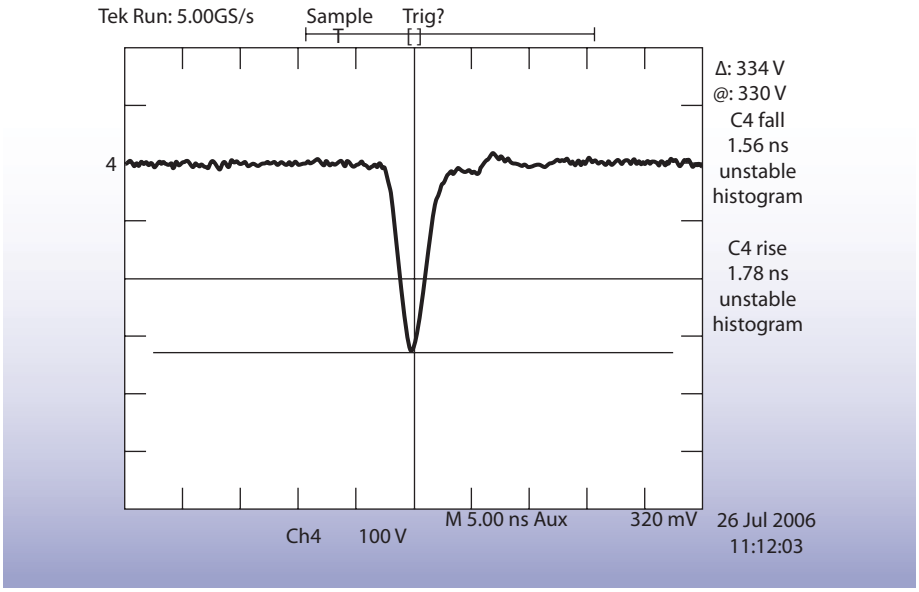

Figure 2. Pulse width results with gate-drive circuit layout.